SPECIFICATION

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Flow Directing Device

Federal Research Statement

The U.S. Government may have rights in this invention pursuant to Contract Number F33615-98-2-2905 with the United States Air Force.

Background of Invention

[0001] This invention relates to flow directing devices for use in gas turbine engines. Specifically, the present invention relates to an apparatus and a method of reducing heat load on an airfoil exposed to a gas flow.

[0002] The major components of a gas turbine engine include (beginning at the upstream end, or inlet) a fan section, one or more compressor sections, a burner section, one or more turbine sections, and a nozzle. The engine may also include an afterburner.

[0003] Air enters the engine through the inlet, travels past the fan section, becomes compressed by the compressor sections, mixes with fuel, and combusts in the burner section. The gases from the burner section drive the turbine sections, then exit the engine through the nozzle to produce thrust. If present, the afterburner could augment the thrust of the engine by igniting additional fuel downstream of the burner section.

[0004] The compressor and turbine sections include a plurality of rotor assemblies and stationary vane assemblies. Rotor blades and stator vanes are examples of structures (i.e., "flow directing structures") that direct core gas flow within a gas turbine engine. Air entering the compressor and traveling aft through the burner and turbine sections is typically referred to as "core gas." In and aft of the burner and turbine sections, the core gas further includes cooling air entering the flow path and the products of combustion products.

[0005] In and aft of the burner section, the high temperature of the core gas requires cooling of the components that contact the core gas. One such cooling schemes passes cooling air internally through the component and allowing it to exit through passages disposed within an external wall of the component. Another such cooling scheme utilizes a film of cooling air traveling along the outer surface of a component. The film of cooling air insulates the component from the high temperature core gas and increases the uniformity of cooling along the component surface.

[0006] Core gas temperature varies significantly within the core gas flow path, particularly in the first few stages of the turbine section aft of the burner section. In the axial direction, core gas temperature decreases in the downstream direction as the distance from the burner section increases. In the radial direction, core gas temperature has a peak at the medial region of the core gas flow path. The radially outer region and the radially inner region of the core gas flow path have the lowest core gas temperatures.

[0007] Various flow anomalies can affect the core gas flow. One such flow anomaly is a "horseshoe vortex." A horseshoe vortex typically forms where an airfoil abuts a surface forming one of the radial boundaries of the gas path, such as the platform of a stator vane. The horseshoe vortex begins along the leading edge area of the airfoil, traveling away from the medial region of the airfoil and towards the stator vane platform. The vortex next rolls away from the airfoil, travelling along the wall against the core gas flow. Subsequently, the vortex curls around to form the namesake flow pattern. The horseshoe vortex detrimentally affects components near the airfoil.

[0008] For example, the horseshoe vortex affects the useful life of the wall. Specifically, the horseshoe vortex augments the heat load of the stator vane platform by urging higher temperature medial region core gas flow to the platform. Unlike the airfoil, the platform lacks any cooling schemes that can offset the augmented heat load.

[0009] The horseshoe vortex also affects the useful life of the burner section. As discussed above, the horseshoe vortex draws higher temperature medial region core gas flow towards the radial boundary of the gas path. Such heat load augmentation may damage the liner in the burner section since the liner is adjacent (albeit upstream) to the stator vane platform.

[0010] Another such flow anomaly is a "passage vortex" that develops in the passage between adjacent airfoils in a stator or rotor section. The passage vortex is an amalgamation of the pressure side portion of the horseshoe vortex, core gas crossflow between adjacent airfoils, and the entrained air from the freesteam core gas flow passing between the airfoils. Collectively, these flow characteristics encourage some percentage of the flow passing between the airfoils to travel along a helical path (i.e., the "passage vortex") that diverts core gas flow from the center of the core gas path toward one or both radial boundaries of the core gas path. As with a horseshoe vortex, the passage vortex draws higher temperature center core gas flow towards the radial boundaries of the core gas path. This detrimentally affects the useful life of the stator vane platform.

[0011] United States Patent number 6,419,446, also owned by assignee of the present application, is an attempt to prevent horseshoe vortex and passage vortex formation. The patent describes the use of a fillet adjacent the stagnation line of the airfoil. While helping prevent horseshoe and passage vortex formation, the fillet does not reduce the heat load on the airfoil.

[0012] A need exists, therefore, for an apparatus and a method of reducing heat load on an airfoil exposed to a gas flow.

Summary of Invention

[0013] It is an object of the present invention to provide an improved flow directing device.

[0014] It is a further object of the present invention to provide a flow directing device and a method of reduced heat load on the flow directing device.

[0015] It is a further object of the present invention to provide a flow directing device that does not produce a horseshoe vortex.

[0016] It is a further object of the present invention to provide a flow directing device that directs gas flow from a lower temperature section of the flow directing device to a higher temperature section of the flow directing device.

[0017] These and other objects of the present invention are achieved in one aspect by a

flow directing device. The device comprises: an airfoil having a leading edge, a trailing edge, a suction side and a pressure side; a wall abutting the airfoil; and a fillet between the airfoil and wall. The fillet has an enlarged section at the leading edge, along the suction and pressure sides, and towards the trailing edge.

[0018] These and other objects of the present invention are achieved in another aspect by a vane segment. The vane segment comprises: at least one platform; a plurality of airfoils extending from the at least one platform, each of the airfoils having a leading edge, a trailing edge, a suction side and a pressure side; and a fillet between each of the airfoils and the platform. Each of the fillets have an enlarged section at the leading edge, along the suction and pressure sides, and towards the trailing edge.

[0019] These and other objects of the present invention are achieved in another aspect by a method of reducing heat load on an airfoil. The method comprises the steps of: providing an airfoil with a proximal end that abuts a wall, a distal end and a medial section between said ends; flowing a gas over the airfoil, the gas adjacent the medial section of said airfoil having a higher temperature than the gas flowing over the proximal end of the airfoil; and directing the gas from the proximal end of the airfoil to the medial section of the airfoil.

Brief Description of Drawings

[0020] Other uses and advantages of the present invention will become apparent to those skilled in the art upon reference to the specification and the drawings, in which:

[0021] Figure 1 is a cross-sectional view of an aircraft gas turbine engine;

[0022] Figure 2 is a perspective view of a conventional flow directing device;

[0023] Figure 3 is a perspective view of one embodiment of a flow directing device of the present invention;

[0024] Figure 4 is an elevational view of the flow directing device of Figure 3;

[0025] Figure 5 is a cross-sectional view of the flow directing device taken along line 5-5 of Figure 4;

[0026] Figure 6 is an elevational view of another flow directing device of the present

invention; and

[0027] Figures 7 and 8 are graphical depictions of temperature contours of a fluid flowing past the flow directing devices of Figures 2 and 3, respectively.

Detailed Description

[0028] Figure 1 displays a gas turbine engine 10. The engine 10 has a fan section 11, compressor section 13, 15, a burner section 17, turbine sections 19, 21 and a nozzle 23. The engine could also include an afterburner 25. The compressor sections 13, 15 and the turbine sections 19, 21 each include alternating arrangements of stator vane stages 27 and rotor stages 29. The stator vane stages 27 guide core gas flow into or out of an adjacent rotor stage 29.

[0029] Figure 2 displays one of the stator vane stages 27. The stage 27 is segmented into stator vane clusters 29. Each cluster 29 has one or more airfoils 31 extending between an inner platform 33 and an outer platform 35. The platforms 33, 35 define the radial boundaries of the annular core gas path through the engine 10.

[0030] The clusters 29 are typically cast into a rough shape, then machined into a final form. The machining process does not create a perpendicular intersection between the airfoil 31 and the platforms 33, 35. Instead, the machining process provides a fillet F between the airfoil 31 and the platforms 33, 35. In other words, the fillet F is the material that fills in at the intersection of two surfaces.

[0031] Like all airfoils, airfoils 31 each have a stagnation line S. The stagnation lines S reside at the front of the airfoils 31 (in terms of core gas flow direction) and identifies the location where the core gas flow has zero velocity. The core gas flow reaching the airfoil 31 on the suction side of the stagnation line S travels along the suction side of the airfoil 31, while core gas flow reaching the airfoil 31 on the pressure side of the airfoil travels along the pressure side of the airfoil 31.The airfoils 31 also have gage points on the pressure side (G_p) and on the suction side (G_s – not seen in Figure 1). The gage points G_p, G_s define the end points of a line (not shown) that defines the minimum distance between adjacent airfoils 31.

[0032]

Figures 3-5 display one embodiment of the present invention. Figure 3 shows a

stator vane cluster 101, which forms one segment of a stator vane stage of a gas turbine engine. The vane cluster 101 has one or more airfoils 103 extending between one or more platforms 105 (for clarity, Figure 3 only shows the inner platform). The platforms 105 define the radial boundaries of the annular core gas path through the engine 10. The airfoils 103 have a suction side 107 and a pressure side 109The clusters 101 are similar to clusters 29. Namely, the clusters 101 have a fillet F between the airfoil 103 and the platforms 105 as a result of the machining process. In addition, the airfoils 103 have stagnation lines S, gage points G_s on the suction sides 107 and gage points G_p on the pressure sides 109.

[0033] As seen in Figure 5, the fillet F extends a distance d from the airfoil 103 around the perimeter thereof. Similarly, the fillet extends a height h along the airfoil 103 around the perimeter thereof.

[0034] Differently than clusters 29, the fillets F of clusters 101 have enlarged sections E and normal sections. Within the normal sections of the fillet F, the distance d and the height h typically remain constant. Within the enlarged sections E of the fillet F, however, the distance d and height h vary independently. Both the distance d and height h preferably follow continuous functions, such as a spline or a cosine. The use of continuous functions ensures that the enlarged section E lacks any discontinuities in slope while varying in curvature around the airfoil 103.

[0035] Distance d can vary between a minimum (d_{min}) and a maximum (d_{max}). The minimum distance d_{min} preferably resides where the enlarged section E transitions to the normal section of the fillet F. This typically occurs near the gage points G_s, G_p. The maximum distance d_{max} preferably resides near the stagnation line S within the enlarged section E. As seen in Figure 5, the maximum distance d_{max} preferably resides to the suction side of the stagnation line S. Certain situations may require the maximum distance d_{max} to reside to the pressure side of the stagnation line S, such as when the airfoil 103 experiences negative incidence. The maximum distance d_{max} is approximately 8 times greater than the minimum distance d_{min}.

[0036] Height h can vary between a minimum (h_{min}) and a maximum (h_{max}). The minimum height h_{min} preferably resides where the enlarged section E transitions to the normal section of the fillet F. This typically occurs near the gage points G_s, G_p.

The maximum height h_{max} preferably resides near the stagnation line S within the enlarged section E. As seen in Figure 4, the maximum height h_{max} resides to the suction side of the stagnation line S. Certain situations may require the maximum height h_{max} to reside to the pressure side of the stagnation line S, such as when the airfoil 103 experiences negative incidence. Typically, the location of maximum height h_{max} corresponds to the location of maximum distance d_{max}. The maximum height h_{max} is approximately 10 times greater than the minimum height h_{min}. Stated differently, the maximum height h_{max} is approximately 30 percent of the span of the airfoil 103.

[0037] As seen in Figure 5, the major extent of the enlarged section E of the fillet F resides at the leading edge of the airfoil 103. However, Figure 5 also shows that the enlarged section E of the fillet F extends downstream along both the suction side 107 and pressure side 109 of the airfoil 103 towards the trailing edge of the airfoil 103. Preferably, the enlarged section E transitions to normal size near the gage points G_s, G_p on both sides 107, 109 of the airfoil 103. By returning to the normal size of fillet F near the gage points G_s, G_p, the present invention does not interfere with the flow capacity of the vane stage. Without reducing the flow area through the stage, the present invention does not alter the exit Mach number nor the reaction of the stage (which impacts thrust load of the turbine).

[0038] Although Figure 5 shows the enlarged section E residing entirely upstream of the gage points G_s, G_p, the present invention contemplates that the enlarged section E could reside both upstream and downstream of the gage points G_s, G_p (not shown). In this arrangement, the enlarged section E would return to a normal size fillet F adjacent the gage points, then return to an enlarged section downstream (not shown).Figure 4 shows that the profile of the enlarged section E of the fillet F is linear. However, Figure 6 shows an alternative embodiment, in which an enlarged section E' of the fillet F has an arcuate profile. Preferably, the arcuate profile of the enlarged section E' of the fillet F is an elliptical shape.

[0039] Although described with respect to the inner platform of the vane cluster 101, the present invention could locate the enlarged sections E, E' of the fillets F on just the outer platform of the vane cluster (not shown in Figures 3-6 for clarity), or both.

[0040] The present invention has clear benefits over conventional designs. As described above, various flow anomalies can affect conventional designs. Figure 7 demonstrates the impact of a horseshoe vortex on core gas flow. The horseshoe vortex draws fluid from the medial region of the airfoil 31 towards the platform 33. This brings hotter core gas flow to the platform 33. The platform 33 is not as capable of withstanding hot core gas flow as is the airfoil. As a result, the hotter core gas flow can damage the platform and structures adjacent (upstream or downstream) of the platform.

[0041] Figure 8 shows that a horseshoe vortex does not exist adjacent the enlarged section E of the fillet F of the present invention. Without the horseshoe vortex, the core gas flow from the medial region of the airfoil 103 does not approach the platform 105. In fact, the enlarged section E of the fillet F of the present invention performs the opposite function. The enlarged section E directs fluid from adjacent the platform 105 towards the medial section of the airfoil 103. This brings cooler core gas flow to the airfoil 103.

[0042] The present invention also has a secondary benefit. The enlarged section E of the fillet E helps delay the development of the passage vortex between adjacent airfoils.

[0043] The present invention has been described in connection with the preferred embodiments of the various figures. It is to be understood that other similar embodiments may be used or modifications and additions may be made to the described embodiment for performing the same function of the present invention without deviating therefrom. Therefore, the present invention should not be limited to any single embodiment, but rather construed in breadth and scope in accordance with the recitation of the appended claims.